

Where is the 3rd subgroup of GRBs?

I. Horváth¹, A. Mészáros², L. G. Balázs³ and Z. Bagoly⁴

¹ *Dept. of Phys., Bolyai Military Univ. H1456 Budapest, POB 12, Hung*

² *Astr. Inst. Charles Univ. V Holešovičkách 2, CZ-180 00 Prague 8*

³ *Konkoly Observatory, H-1525 Budapest, POB 67, Hungary*

⁴ *Laboratory for Information Technology, Eötvös University, H-1117 Budapest, Pázmány P. s. 1./A, Hungary*

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Abstract. It is shown that in the duration-hardness plane the GRBs of the third intermediate subgroup are well defined. Their durations are intermediate (i.e. roughly between 2 and 10 seconds), but their hardnesses are the smallest. They are even softer than the long bursts.

Key words: gamma rays: bursts

1. Introduction

It is widely accepted that the short and long gamma-ray bursts (GRBs) are really different phenomena (see, for example Norris et al. (2001) and the references therein). In 1998 Horváth made a trimodal fit of the BATSE Catalog bursts' duration distribution and found a third subclass of GRBs' (Horváth 1998). Later papers (Mukherjee et al. 1998, Hakkila et al. 2000, Rajaniemi & Mähönen 2002, Horváth 2002) used more parameters (e.g. peak fluxes, fluences, hardness ratios), and in this multidimensional space studies all of them confirmed that the third bursts population was statistically necessary.

Bagoly et al. (1998) showed that in this high dimensional parameter spaces only two main parameters were necessary to characterize all the BATSE Catalog bursts' properties. Hence, a two dimensional space looks like a good characterisation of the GRB subgroups. Therefore, here we use T_{90} and the hardness H_{32} ratio in our newest analysis. Figure 1. shows the observed BATSE bursts' distribution on the $\log(T_{90}) - \log(H_{32})$ plane.

2. The fits

This distribution can be fitted at the first step by the sum of two two-dimensional normal distributions in the $\log T_{90}$ - $\log H32$ plane. If one were fitting *simultaneously* the values of $\log T_{90}$ and $\log H32$ by one single two-dimensional (bivariate) normal distribution, then the distribution would have five independent parameters (two means, two dispersions, and the correlation coefficient). The standard form of such a bivariate distribution is given by

$$f(x, y)dx dy = \frac{N dx dy}{2\pi\sigma_x\sigma_y\sqrt{1-r^2}} \times \exp \left[-\frac{1}{2(1-r^2)} \left(\frac{(x-a_x)^2}{\sigma_x^2} + \frac{(y-a_y)^2}{\sigma_y^2} - \frac{C}{\sigma_x\sigma_y} \right) \right], \quad (1)$$

where $x = \log T_{90}$, $y = \log H32$, $C = 2r(x-a_x)(y-a_y)$, a_x , a_y are the means, σ_x , σ_y are the dispersions, and r is the correlation coefficient. N is the number of GRBs, and $f(x, y)dx dy$ the theoretically expected numbers of GRBs at the inf. surface at the $[x, y]$ plane given by intervals $[x, (x+dx)]$ and $[y, (y+dy)]$. In other words, $(f(x, y)/N)dx dy$ defines the probability of finding a GRB at the given inf. surface.

Table 1. Best fit with two bivariate normal distributions for $\log T_{90}$ and $\log H32$.

| | | | |
|---------------|-------|---------------|------|
| a_{x1} | -0.35 | a_{x2} | 1.47 |
| a_{y1} | 0.70 | a_{y2} | 0.39 |
| σ_{x1} | 0.52 | σ_{x2} | 0.47 |
| σ_{y1} | 0.33 | σ_{y2} | 0.24 |
| r_1 | 0.1 | r_2 | 0.1 |
| W | 0.28 | | |

the weight of the first normal distribution. For the first (second) term the parameters are $a_{x1}, a_{y1}, \sigma_{x1}, \sigma_{y1}, r_1$ ($a_{x2}, a_{y2}, \sigma_{x2}, \sigma_{y2}, r_2$).

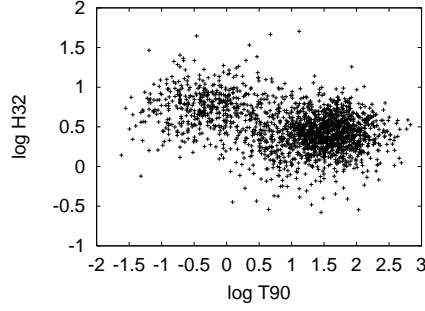


Fig. 1. The values of $\log T_{90}$ and $\log H32$ of the 1929 BATSE GRBs.

We obtain the best fit to the 11 parameters through a maximum likelihood (ML) estimation. We search for the maximum of the formula

$$L_2 = \sum_{i=1}^N \ln f_2(x_i, y_i) \quad (2)$$

using a simplex numerical procedure; the index "2" in L_2 shows that we have a sum of two log-normal distributions of type given by Eq.1.

The results of this fit are shown in Table 1. One can calculate a density distribution of the observed data on the $\log(T_{90})$ - $\log(H_{32})$ plane. The values of Table 1 define the theoretical distribution of GRBs, if there is any theory, which suggests lognormal H_{32} and T_{90} distributions, in the T_{90} - H_{32} plane under the assumption that there are *only* two subgroups.

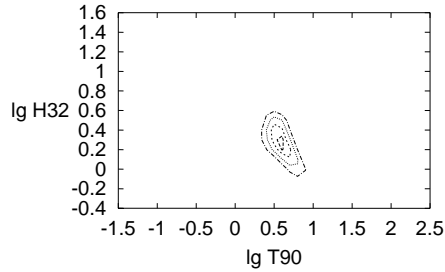


Fig. 1. Departure of the numbers of GRBs from the theoretical values given by the best fit collected at Table 1.

Hence, one can make the difference between the actual distribution and the theoretical distribution. If there were only two components, which distributed lognormally, one would find only some noise being proportional to the square root of the actual value of the burst density function. Surprisingly the biggest deviation is not there where the observed (or the theoretical) burst density function is the biggest, not even the dense core of the two subgroup population, rather then between the two groups in T_{90} but in H_{32} softer then either groups.

This deviation is shown by Figure 2. The widest contour has the half intensity then the highest deviation. In order to be sure that this difference is not a chance and is not given by the random noise, we proceeded as follows. We take this part of the $\log T_{90}$ - $\log H_{32}$ plane. This part contains 145 bursts. The integral over this area of the theoretical distribution gives 63.

Depends on which number is the Poisson parameter one can calculate the probability 10^{-17} - 10^{-14} . Of course there are so many different area and shapes, which we can probe. However if we take

10 different shapes 100 different sizes and try 1000 different positions in the plane the probability is still very low. Therefore one can say the deviation which the Figure 2. shows is very unlikely can cause by chance.

Unfortunately, the possible third group members are mixed with the long ones (partially also with the short ones, too).

3. Conclusions

We have argued that both the duration and also the hardness should be distributed log-normally - of course, in any subclass separately. We also provided in the $\log T_{90}$ - $\log H32$ plane a fit with the sum of two bivariate normal distributions. The idea for this fitting was given by the observational fact that the short and long subclasses are different both at hardnesses and durations. Finally we obtained the difference between the actual distribution of GRBs and the theoretical one. The difference, not being a Poissonian noise, shows another subgroup, the third subgroup.

As the result we obtained the intermediate subclass having approximately the same number of bursts than it was previously predicted (Horváth 1998, Mukherjee et al. 1998, Hakkila et al. 2000, Rajaniemi & Mähönen 2002 and Horváth 2002). We also confirm that their hardnesses are low.

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